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Ritchie et al.

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(54) **METHODS FOR DEPOSITING METAL IN HIGH ASPECT RATIO FEATURES**

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H01L 21/44 (2006.01)

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(52) **U.S. Cl.**

CPC ***H01L 21/76898*** (2013.01); ***H01L 21/2855*** (2013.01); ***H01J 37/3408*** (2013.01); ***H01L 21/76865*** (2013.01); ***C23C 14/34*** (2013.01); ***C23C 14/046*** (2013.01); *C23C 16/56* (2013.01); ***C23C 14/354*** (2013.01); ***C23C 16/503*** (2013.01); ***C23C 14/3492*** (2013.01); *H01J 2237/3327* (2013.01); ***H01L 21/76873*** (2013.01); ***C23C 14/345*** (2013.01); ***C23C 16/52*** (2013.01)

USPC **438/109**; 438/629; 438/643; 438/653; 438/667; 438/672; 438/678; 438/687; 438/695; 438/696; 204/192.3

(58) **Field of Classification Search**

USPC 438/109, 629, 643, 653, 667, 672, 678, 438/687, 695, 696; 257/E21.584, E21.585, 257/E21.589, E21.597

See application file for complete search history.

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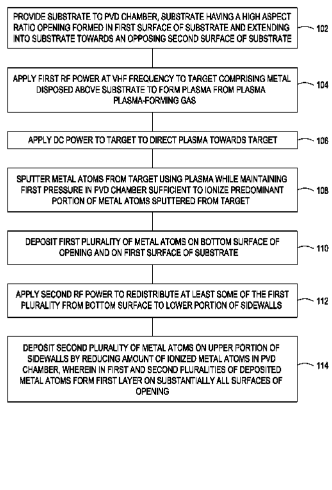
(57) **ABSTRACT**

Methods for depositing metal in high aspect ratio features formed on a substrate are provided herein. In some embodiments, a method includes applying first RF power at VHF frequency to target comprising metal disposed above substrate to form plasma, applying DC power to target to direct plasma towards target, sputtering metal atoms from target using plasma while maintaining pressure in PVD chamber sufficient to ionize predominant portion of metal atoms, depositing first plurality of metal atoms on bottom surface of opening and on first surface of substrate, applying second RF power to redistribute at least some of first plurality from bottom surface to lower portion of sidewalls of the opening, and depositing second plurality of metal atoms on upper portion of sidewalls by reducing amount of ionized metal atoms in PVD chamber, wherein first and second pluralities form a first layer deposited on substantially all surfaces of opening.

20 Claims, 4 Drawing Sheets



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H01J 37/34	(2006.01)
H01L 21/768	(2006.01)
C23C 14/34	(2006.01)
C23C 14/04	(2006.01)
C23C 14/35	(2006.01)
C23C 16/503	(2006.01)
C23C 16/52	(2006.01)
C23C 16/56	(2006.01)

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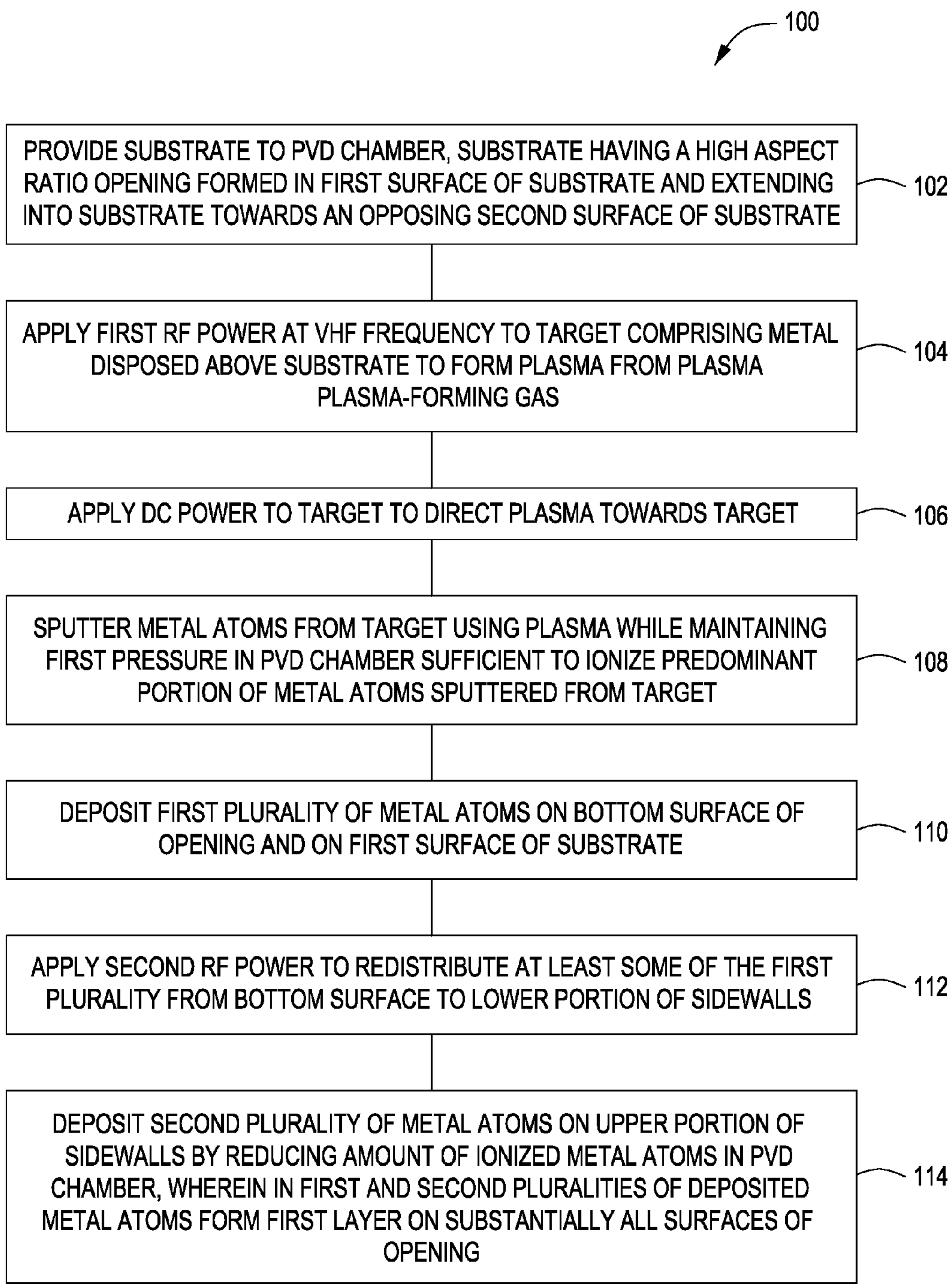
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PROVIDE SUBSTRATE TO PVD CHAMBER, SUBSTRATE HAVING A HIGH ASPECT RATIO OPENING FORMED IN FIRST SURFACE OF SUBSTRATE AND EXTENDING INTO SUBSTRATE TOWARDS AN OPPOSING SECOND SURFACE OF SUBSTRATE
102
APPLY FIRST RF POWER AT VHF FREQUENCY TO TARGET COMPRISING METAL DISPOSED ABOVE SUBSTRATE TO FORM PLASMA FROM PLASMA PLASMA-FORMING GAS
104
APPLY DC POWER TO TARGET TO DIRECT PLASMA TOWARDS TARGET
106
SPUTTER METAL ATOMS FROM TARGET USING PLASMA WHILE MAINTAINING FIRST PRESSURE IN PVD CHAMBER SUFFICIENT TO IONIZE PREDOMINANT PORTION OF METAL ATOMS SPUTTERED FROM TARGET
108
DEPOSIT FIRST PLURALITY OF METAL ATOMS ON BOTTOM SURFACE OF OPENING AND ON FIRST SURFACE OF SUBSTRATE
110
APPLY SECOND RF POWER TO REDISTRIBUTE AT LEAST SOME OF THE FIRST PLURALITY FROM BOTTOM SURFACE TO LOWER PORTION OF SIDEWALLS
112
DEPOSIT SECOND PLURALITY OF METAL ATOMS ON UPPER PORTION OF SIDEWALLS BY REDUCING AMOUNT OF IONIZED METAL ATOMS IN PVD CHAMBER, WHEREIN IN FIRST AND SECOND PLURALITIES OF DEPOSITED METAL ATOMS FORM FIRST LAYER ON SUBSTANTIALLY ALL SURFACES OF OPENING
114

FIG. 1

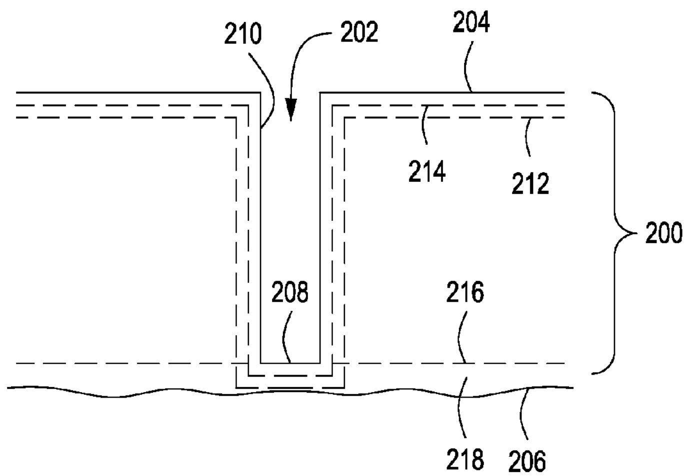

FIG. 2A

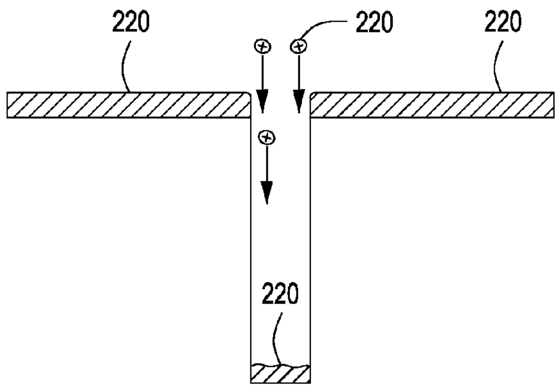

FIG. 2B

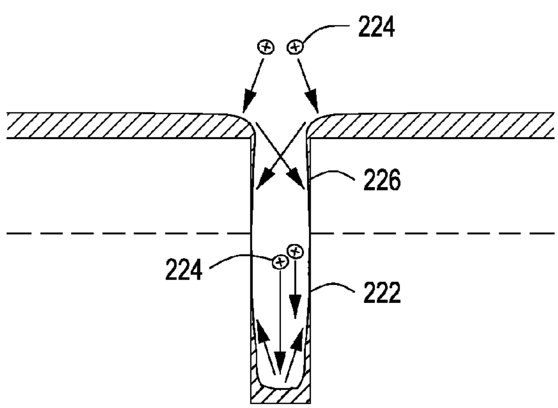

FIG. 2C

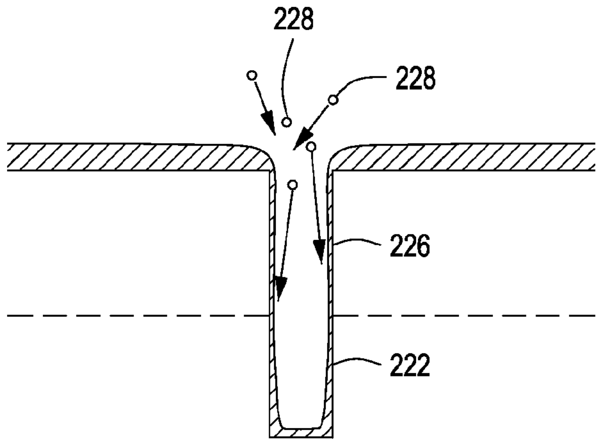

FIG. 2D

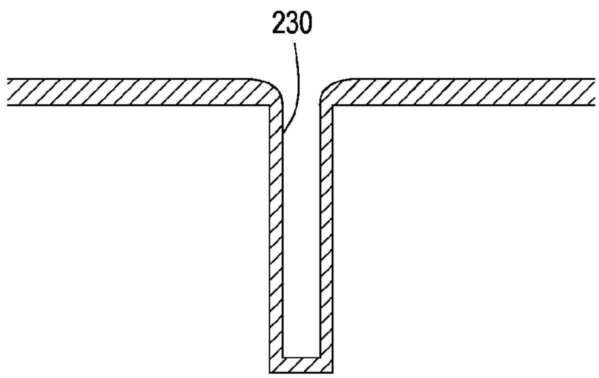

FIG. 2E

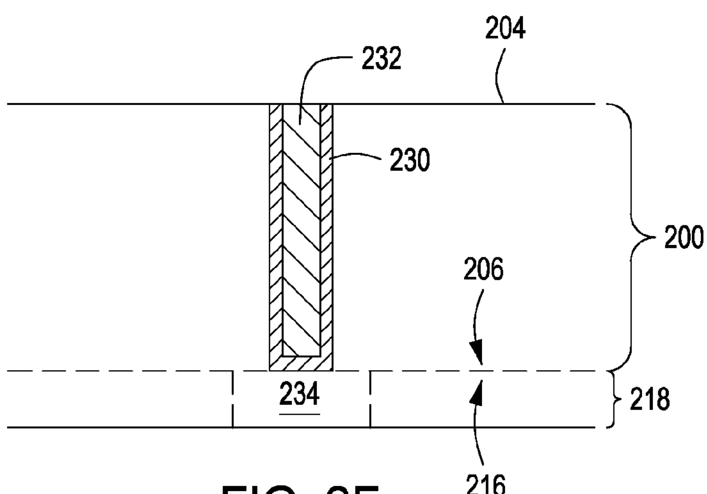

FIG. 2F

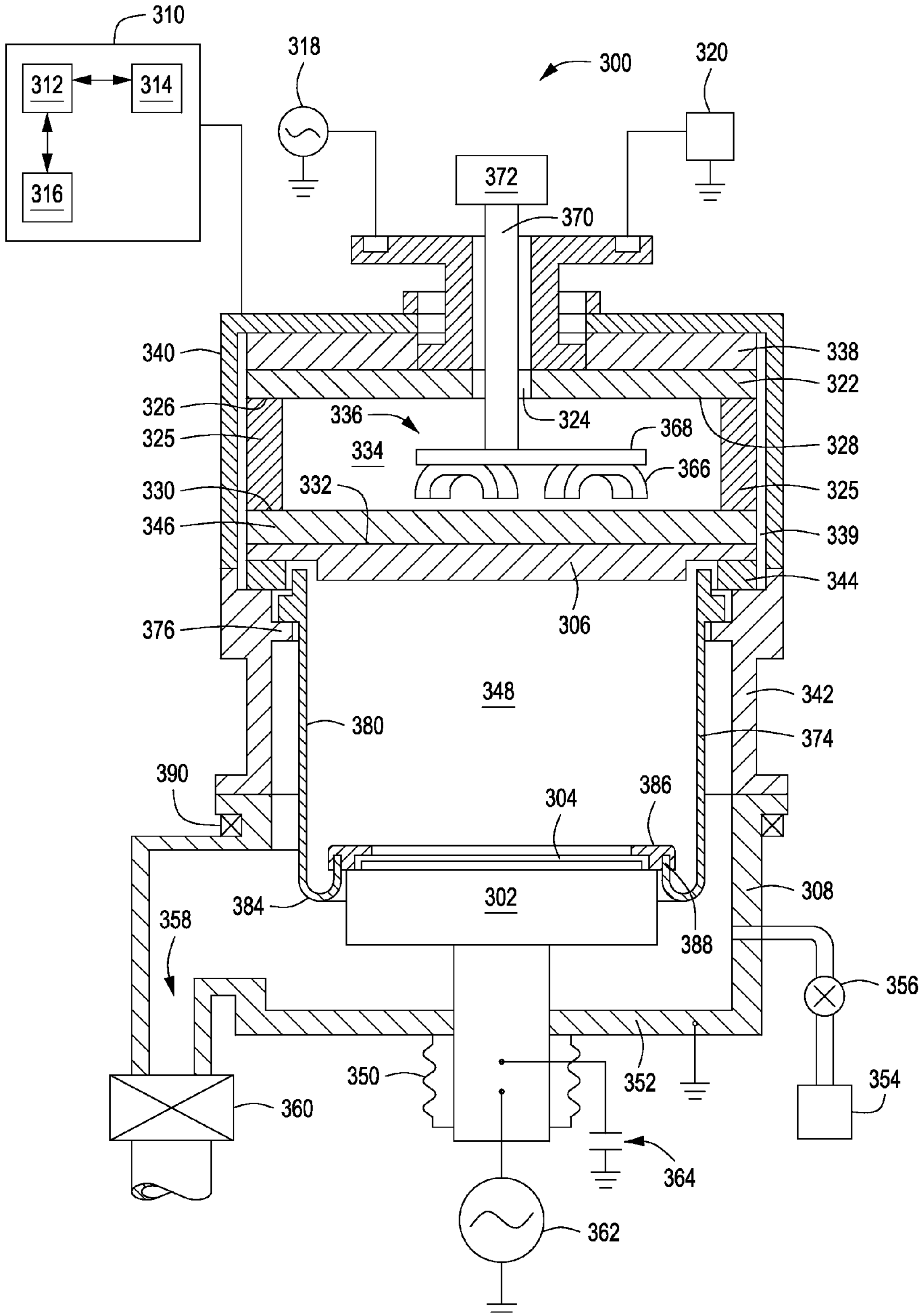
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FIG. 3

METHODS FOR DEPOSITING METAL IN HIGH ASPECT RATIO FEATURES

CROSS-REFERENCE TO RELATED APPLICATIONS

This application claims benefit of U.S. provisional patent application Ser. No. 61/369,240, filed Jul. 30, 2010, which is herein incorporated by reference

FIELD

Embodiments of the present invention generally relate to methods of depositing metal in high aspect ratio features formed on a substrate.

BACKGROUND

Through-silicon via (TSV) or similar technologies require a continuous metal-containing layer to be deposited within a high aspect ratio feature on a substrate. For example, the metal-containing layer to be deposited may be a barrier layer to prevent diffusion of materials from the feature into the substrate or a seed layer which may be used as a template for filling the feature by electroplating or other suitable techniques. High aspect ratio features, for example, may include features having an aspect ratio of about 5:1 or greater. Unfortunately, the inventors have discovered that conventional direct current (DC) sputtering, such as performed in a DC physical vapor deposition (DC PVD) chamber does not provide adequate coverage to the bottom surface of a high aspect ratio feature. For example, the inventors have discovered for some metals, such as titanium (Ti), tantalum (Ta), or copper (Cu), the bottom surface coverage can be less than about 3%. The lack of continuous surface coverage in the feature can result in void formation during the filling of the feature. Further, while DC PVD process conditions can be modified to achieve acceptable bottom surface coverage, the conditions require long deposition times as well as exposing the substrate to elevated temperatures, which significantly impact the cost per substrate and undesirably expose the substrate to elevated temperatures causing undesirable diffusion of materials between existing regions of the substrate.

Accordingly, the inventors have developed improved techniques to deposit continuous metal-containing layers in high aspect ratio features.

SUMMARY

Methods for depositing metal in high aspect ratio features formed on a substrate are provided herein. In some embodiments, a method of processing a substrate in a physical vapor deposition (PVD) chamber, the substrate having an opening formed in a first surface of the substrate and extending into the substrate towards an opposing second surface of the substrate, the opening having an aspect ratio of height to width of at least 5:1 is provided. In some embodiments, the method may include applying a first RF power at a VHF frequency to a target comprising a metal disposed above the substrate to form a plasma from a plasma-forming gas; applying DC power to the target to direct the plasma towards the target; sputtering metal atoms from the target using the plasma while maintaining a first pressure in the PVD chamber sufficient to ionize a predominant portion of the metal atoms sputtered from the target; depositing a first plurality of metal atoms on a bottom surface of the opening and on the first surface of the substrate; applying a second RF power to a first electrode disposed beneath the substrate to redistribute at least some of the first plurality of metal atoms from the bottom surface to a lower portion of a sidewall of the opening; and depositing a second plurality of metal atoms on an upper portion of the sidewall by reducing an amount of ionized metal atoms in the PVD chamber, wherein the first and second pluralities of metal atoms form a first layer deposited on substantially all surfaces of the opening.

Other and further embodiments of the present invention are described below.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the present invention, briefly summarized above and discussed in greater detail below, can be understood by reference to the illustrative embodiments of the invention depicted in the appended drawings. It is to be noted, however, that the appended drawings illustrate only typical embodiments of this invention and are therefore not to be considered limiting of its scope, for the invention may admit to other equally effective embodiments.

FIG. **1** depicts a flow chart of a method for processing a substrate in accordance with some embodiments of the present invention.

FIGS. **2**A-F depicts the stages of filling a high aspect ratio opening in accordance with some embodiments of the present invention.

FIG. **3** depicts a schematic, cross-sectional view of a physical vapor deposition (PVD) chamber in accordance with some embodiments of the present invention.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures. The figures are not drawn to scale and may be simplified for clarity. It is contemplated that elements and features of one embodiment may be beneficially incorporated in other embodiments without further recitation.

DETAILED DESCRIPTION

Methods for depositing metals in high aspect ratio features formed on substrates are provided herein. The inventive methods advantageously provide continuous coverage of surfaces of the high aspect ratio feature with metal while maintaining high process throughput and low substrate temperature. The inventive methods may be utilized with through silicon via (TSV) applications, for example, for either via first or via last methods of fabrication, as well as other suitable applications where depositing a continuous metal layer in high aspect ratio openings may be desired.

FIG. **1** depicts a flow chart of a method **100** for processing a substrate in accordance with some embodiments of the present invention. The method **100** is described below with respect to the stages of filling a high aspect ratio feature as depicted in FIG. **2**. Further, the method **100** may be performed in any suitable PVD process chamber having both DC and radio frequency (RF) power sources, such as a process chamber **300** described below and depicted in FIG. **3**.

The method **100** begins at **102** by providing a substrate **200** to a PVD chamber, for example process chamber **300**. The substrate **200** includes a high aspect ratio opening **202** formed in a first surface **204** of the substrate **200** and extending into the substrate **200** towards an opposing second surface **206** of the substrate **200**. The substrate **200** may be any suitable substrate having a high aspect ratio opening formed therein. For example, the substrate **200** may comprise one or more of silicon (Si), silicon oxide (SiO_2), or the like. In addition, the substrate **200** may include additional layers of materials or may have one or more completed or partially completed structures formed therein or thereon.

The opening may be any opening having a high aspect ratio, such as a via, trench, dual damascene structure, or the like. In some embodiments, the opening **202** may have a height to width aspect ratio of at least about 5:1 (e.g., a high aspect ratio). For example, in some embodiments, the aspect ratio may be about 10:1 or greater, such as about 15:1. The opening **202** may be formed by etching the substrate using any suitable etch process. The opening **202** includes a bottom surface **208** and sidewalls **210** as shown.

In some embodiments, the bottom surface **208** and the sidewalls **210** may be covered with one or more layers prior to depositing metal atoms as described below. For example, and as shown by dotted lines in FIG. **2**A, the bottom surface and sidewalls of the opening **202** and the first surface of the substrate **200** may be covered by an oxide layer **212**, such as silicon oxide (SiO_2) or the like. The oxide layer may be deposited or grown, for example in a chemical vapor deposition (CVD) chamber or in a oxidation chamber, prior to providing the substrate **200** to a PVD chamber. The oxide layer **212** may serve as an electrical and/or physical barrier between the substrate and a metal-containing layer to be subsequently deposited in the opening, and/or may function as a better surface for attachment during the deposition process discussed below than a native surface of the substrate.

In some embodiments, a barrier layer **214** may be deposited atop the oxide layer **212** (as shown), or atop the bottom surface and sidewalls of the opening and the first surface of the substrate if an oxide layer is not present. The barrier layer **214** may serve a similar purpose as the oxide layer **212** discussed above. In some embodiments, the barrier layer **214** may include at least one of titanium (Ti), tantalum (Ta), cobalt (Co), oxides or nitrides of Ti, Ta, and/or Co, or the like. The barrier layer **214** may be deposited by any suitable methods, such as by CVD or PVD, including by using the method **100** described below to form a continuous barrier layer in the opening **202**.

In some embodiments, and as illustrated in phantom in FIG. **2**A, the opening **202** may extend completely through the substrate **200** and an upper surface **216** of a second substrate **218** may form the bottom surface **208** of the opening **202**. The second substrate **218** may be disposed adjacent to the second surface **206** of the substrate **200**. Further (as shown in FIG. **2**F and discussed below), a device, such as a logic device or the like, or a portion of a device requiring electrical connectivity, such as a gate, a contact pad, a conductive via, or the like, may be disposed in the upper surface **216** of the second substrate **218** and aligned with the opening **202**.

At **104**, a first RF power (such as from an RF power source **318**, described below) is applied at a VHF frequency to a target comprising a metal disposed above the substrate **200** to form a plasma from a plasma-forming gas. For example, the target may be the target **306** discussed below. The target may comprise one or more of metals, metal alloys, or the like, of suitable purity to form a continuous barrier layer or seed layer of a desired material on the surfaces of the opening **202** and the first surface **204** of the substrate **200**. For example, the target may comprise titanium (Ti), tantalum (Ta), copper (Cu), aluminum (Al), cobalt (Co), tungsten (W), alloys thereof, or the like. The plasma-forming gas may include argon (Ar), neon (Ne), krypton (Kr), helium (He), hydrogen (H_2), nitrogen (N_2) or the like, or combinations thereof.

The first RF power may be applied at a VHF frequency for one or more of forming the plasma from the plasma-forming gas and ionizing metal atoms sputtered from the target by the plasma. As used herein, a VHF frequency is a frequency in the range of from about 27 MHz to about 162 MHz. In some embodiments, the VHF frequency applied is about 60 MHz. Increasing the VHF frequency may increase the plasma density and/or the amount of ionization in metal atoms sputtered from the target.

At **106**, DC power is applied to the target, for example, from a DC power source **320** coupled to the target **306**, as described below with respect to FIG. **3**. The DC power may bias the target to facilitate directing the plasma towards the target. The DC power may range in magnitude from about 1 to about 4 kilowatts (kW). In some embodiments, the DC power may be about 2 kW. The DC power may be adjusted to control the deposition rate of sputtered metal atoms on the substrate. For example, increasing the DC power can result in increased interaction of the plasma with the target and increased sputtering of metal atoms from the target.

At **108**, metal atoms are sputtered from the target using the plasma while maintaining a first pressure in the PVD chamber sufficient to ionize a predominant portion of metal atoms being sputtered from the target. For example, a predominant portion of metal atoms may range from about 50 to about 75 percent of the total number of metal atoms arriving at the wafer. In some embodiments, and for example, metal atoms initially sputtered from the target may be mostly non-ionized, only once they have passed through the plasma will metal atoms become ionized. For example, a majority of neutral metal atoms will be lost to shields of the process chamber, so metal atoms arriving at the wafer should be predominantly ionized. The first pressure, in addition to the first RF power and the DC power applied, may be dependent on process chamber geometry (such as substrate size, target to substrate distance, and the like). For example, the first pressure may range from about 60 to about 300 millitorr (mT) in a chamber configured with a target to substrate gap of about 60 millimeters (mm). In some embodiments, the first pressure is about 100 mT. The first pressure in the chamber may be maintained by the flow rate of the plasma-forming gas and/or the flow rate of an additional gas, such as an inert gas, which may be co-flowed with the plasma-forming gas. The first pressure may provide a high density of gas molecules between the target and the substrate with which sputtered metal atoms may collide and be ionized. Pressure may be additionally utilized to control the amount of ionization of metal atoms sputtered from the target. For example, increasing pressure in the chamber and/or increasing the target to substrate gap may increase the number of collisions with metal atoms and thus increase the amount of ionized metal atoms.

At **110**, a first plurality of metal atoms **220** are deposited on the upper surface **204** of the substrate **200** and on the bottom surface **208** of the opening **202**, as illustrated in FIG. **2**B. The first plurality of metal atoms **220** may be deposited using the processing conditions discussed above, such as the first pressure, first RF power, DC power, and/or the VHF frequency. Such processing conditions can facilitate the direction of the first plurality of metal atoms **220** approximately perpendicular to substrate **200** as illustrated in FIG. **2**B. In some embodiments, an optional third RF power may be applied to the substrate **200** during the deposition of the first plurality of metal atoms **220**. The third RF power may be applied at a frequency ranging from about 400 kHz to about 27 MHz and at a power of up to about 50 W. In some embodiments, the frequency of the third RF power may be about 2 MHz, or about 13.56 MHz, or both if an optional second RF power source is additionally coupled a substrate support pedestal of the PVD chamber. The optional third RF power may be small to minimize energy of the depositing metal atoms such as to minimize any overhang formation over a mouth of the opening **202**.

Alternatively, another optional embodiment for achieving a similar result as applying optional third RF power, is to use a tuning circuit which may be attached to the substrate support. The tuning circuit (LC) can be used to vary the impedance of an existing substrate support tuning circuit, which couples an RF bias source to the substrate support, to accept or reject current from the plasma. The arrival energy of ionized species can be tailored by varying the reactance, to achieve a low energy or high energy process, which equates to low or high bias power.

At **112**, a second RF power is applied to redistribute at least some of the first plurality of metal atoms **220** from the bottom surface **208** of the opening **202** to a lower portion **222** of the sidewalls **210** of the opening **202**, as illustrated in FIG. **2**C. The lower portion **222** may include about the lower 50 percent of the sidewalls **210** of the opening **202**. The second RF power may be applied at the same frequencies discussed above at **110**. The second RF power may be utilized to increase ion energy and/or angle of incidence of ions **224** incident on the substrate **200** as shown in FIG. **2**C. For example, the ions incident on the substrate **200** may include ionized metal atoms, ionized elements from the plasma, or a combination thereof. The second RF power may be increased to increase ion energy, for example, to increase the impact of ions on the deposited metal atoms on the bottom surface **208** of the opening **202**, as illustrated in FIG. **2**B. The increased impact of ions on the bottom surface **208** of the opening can facilitate redistribution of at least some of the first plurality of metal atoms **220** of metal atoms onto the lower portion **222** as shown. A magnitude of the second RF power may be substantially greater than that of the optional third RF power applied during the deposition of the first plurality of metal atoms **220** as discussed above. For example, a magnitude of the second RF power may be greater than about 50 Watts, or range from about 100 to about 400 watts. In some embodiments, the magnitude of the second RF power is about 200 watts.

In some embodiments, as illustrated in FIG. **2**C, at least some of the first plurality of metal atoms **220** may be redistributed from the upper surface **204** of the substrate **200** into the opening **202**. For example, as shown in FIG. **2**C, due to the non-perpendicular angle of incidence of the incident ions **224** with respect to the substrate **200** due at least in part to the applied second RF power, at least some of the first plurality of metal atoms **220** may be redistributed from the upper surface **204** to an upper portion **226** of the sidewalls **210** of the opening **202**.

Further, in some embodiments, the DC power is maintained to continue to sputter metal atoms from the target using the plasma while redistributing at least some of the first plurality of metal atoms **220** to the lower portion **222** at **112**. Alternatively or in combination, at least one of the first RF power or the first pressure may be maintained to continue deposition of the first plurality of metal atoms **220** while redistributing at least some of the first plurality of metal atoms **220** at **112**. In some embodiments, the first pressure is reduced to a second pressure to reduce the amount of ionized metal atoms incident on the substrate **200**. The second pressure may range from about 40 to about 80 mTorr.

Alternatively, the deposition of the first plurality of metal atoms **220** may be substantially reduced or may cease during redistribution at **112**. For example, and in some embodiments, the DC power applied to the target may be reduced or turned off during redistribution to prevent sputtering of metal atoms from the target. Such embodiments may be utilized to reduce the thickness a layer of deposited metal atoms on the upper surface **204** or the bottom surface **208** during redistribution. Accordingly, in this alternative embodiment, the ions **224** incident on the substrate **200** may substantially comprise ionized elements of the plasma-forming gas.

At **114**, a second plurality of metal atoms **228** is deposited on the upper portion **226** of the sidewalls **210** by reducing the amount of ionized metal atoms in the PVD chamber (shown in FIG. **2**D), wherein the first and second pluralities of metal atoms **220**, **228** together form a first layer **230** deposited on substantially all surfaces of the opening **202** (shown in FIG. **2**E). The upper portion **226** may include about the upper 50 percent of the sidewalls **210** of the opening **202**. The deposition of the second plurality of metal atoms **228** may include one or more of reducing the first RF power, the first pressure, or increasing the DC power to achieve depositing of the second plurality of metal atoms **228** on the upper portion **226** of the sidewalls **210**. For example, and in some embodiments, the first pressure may be reduced to a third pressure, or alternatively, the second pressure may be reduced to the third pressure, if the first pressure has already been reduced as discussed above. In some embodiments, the third pressure may range from about 10 to about 40 mTorr. For example, the third pressure may be sufficient to decrease the amount of ionized metal atoms, which in term increases the amount of neutral metal atoms in the second plurality of metal atoms **228** incident on the substrate **200**. The neutral metal atoms, which have no charge, may not be subject to external applied forces, such as from the plasma, substrate RF bias, or the like. Accordingly, at least some of the neutral metal atoms may be incident at non-perpendicular angles to the substrate **200** and deposit on the upper portion **226**, as illustrated in FIG. **2**D.

Alternatively, or in combination with reducing pressure in the PVD chamber during deposition of the second plurality of metal atoms **228**, the first RF power may be reduced from a first magnitude to a second magnitude to reduce at least one of the amount of ionized metal atoms in the PVD chamber or the amount of sputtered metal atoms in the PVD chamber. In some embodiments, the second magnitude may range from about 1 kW to about 3 kW.

Alternatively, or in combination with any of the above embodiments for depositing the second plurality of metal atoms **228**, the DC power may be reduced from a first magnitude to a second magnitude to reduce the amount of ionized metal atoms in the PVD chamber by reducing the amount of sputtered metal atoms in the PVD chamber. In some embodiments, the second magnitude may range from about 0.5 to about 2 kW.

Alternatively, or in combination with any of the above embodiments for depositing the second plurality of metal atoms **228**, the second RF power may be reduced from a first magnitude to a second magnitude or to a magnitude of zero, to reduce or prevent ionized species, such as ionized elements of the plasma-forming gas, from removing deposited metal atoms from the upper portion **226** of the opening **202**. In some embodiments, the second magnitude of the second RF power may be about less than 50 W.

After the first layer **230** is formed at **114**, the method **100** may proceed by depositing a material **232** atop the first layer **230** to fill the opening **202** by electroplating or a similar processing technique, as depicted in FIG. **2**F. The first layer **230** may function as a seed layer upon which the material **232** is deposited. The material **232** may include metals, metal alloys, or the like. In some embodiments, the material comprises one or more of copper (Cu), tungsten (W), or the like. In some embodiments, the material **232** and the metal of the first layer **230** are the same material.

In some embodiments, and as discussed above with respect to FIG. **2**A, the second substrate **218** may have been provided prior to performing the methods steps **104**-**114** described above. Accordingly, as illustrated in FIG. **2**F, the second substrate **218** is disposed adjacent to the second surface **206** of the substrate **200**, where the opening **202** extends completely through the substrate **200** and the upper surface **216** of the second substrate **218** forms the bottom surface of the opening **202**. In some embodiments, a device **234** may be disposed in the upper surface **216** of the second substrate and aligned with the opening **202**. The first surface **204** of the substrate **200** may be further processed to remove excess material **232** from the fill process, deposited metal atoms, portions of other layers that may be present (such as the oxide layer **212** and/or the barrier layer **214**). For example, chemical mechanical polishing, lapping, etching, or the like may be used to remove the undesired materials and exposing the first surface **204**, as illustrated in FIG. **2**F.

Alternatively, in some embodiments, the second substrate **218** may not have been provided prior to performing method steps **104**-**114**. In such embodiments, and after the material **232** has been deposited as described above, the method may proceed by removing material from the second surface **206** of the substrate **200** to remove the bottom surface **208** of the opening **202** and expose at least one the first layer **230** or the deposited material **232** (the first layer **230** is illustrated as being exposed in FIG. **2**F). For example, material may be removed from the second surface **206** of the substrate **200**, for example, by chemical mechanical polishing, lapping, or the like, to expose at least one of the first layer **230** or the deposited material **232**.

After the removal of material from the second surface **206**, the second surface **206** of the substrate **200** may be coupled to the upper surface **216** of the second substrate **218**. In embodiments where the device **234** is disposed in the upper surface **216** of the second substrate **218**, the device **234** may be aligned with the opening **202** in the substrate **200**.

FIG. **3** depicts a schematic, cross-sectional view of a physical vapor deposition chamber (process chamber **300**) in accordance with some embodiments of the present invention. Examples of suitable PVD chambers include the ALPS® Plus and SIP ENCORE® PVD process chambers, both commercially available from Applied Materials, Inc., of Santa Clara, Calif. Other process chambers from Applied Materials, Inc. or other manufactures may also benefit from the inventive apparatus disclosed herein.

The process chamber **300** contains a substrate support pedestal **302** for receiving a substrate **304** thereon, and a sputtering source, such as a target **306**. The substrate support pedestal **302** may be located within a grounded enclosure, which may be a chamber wall **308** (as shown) or a grounded shield (a ground shield **340** is shown covering at least some portions of the chamber **300** above the target **306**. In some embodiments, the ground shield **340** could be extended below the target to enclose the pedestal **302** as well.).

In some embodiments, the process chamber includes a feed structure for coupling RF and DC energy to the target **306**. The feed structure is an apparatus for coupling RF and DC energy to the target, or to an assembly containing the target, for example, as described herein. A first end of the feed structure can be coupled to an RF power source **318** and a DC power source **320**, which can be respectively utilized to provide RF and DC energy to the target **306**. For example, the DC power source **320** may be utilized to apply a negative voltage, or bias, to the target **306**. In some embodiments, RF energy supplied by the RF power source **318** may range in frequency from about 2 MHz to about 60 MHz, or, for example, non-limiting frequencies such as 2 MHz, 13.56 MHz, 27.12 MHz, 40.68 MHz or 60 MHz can be used. In some embodiments, a plurality of RF power sources may be provided (i.e., two or more) to provide RF energy in a plurality of the above frequencies. The feed structure may be fabricated from suitable conductive materials to conduct the RF and DC energy from the RF power source **318** and the DC power source **320**.

In some embodiments, the feed structure may have a suitable length that facilitates substantially uniform distribution of the respective RF and DC energy about the perimeter of the feed structure. For example, in some embodiments, the feed structure may have a length of between about 1 to about 12 inches, or about 4 inches. In some embodiments, the body may have a length to inner diameter ratio of at least about 1:1. Providing a ratio of at least 1:1 or longer provides for more uniform RF delivery from the feed structure (i.e., the RF energy is more uniformly distributed about the feed structure to approximate RF coupling to the true center point of the feed structure. The inner diameter of the feed structure may be as small as possible, for example, from about 1 inch to about 6 inches, or about 4 inches in diameter. Providing a smaller inner diameter facilitates improving the length to ID ratio without increasing the length of the feed structure.

The second end of the feed structure may be coupled to a source distribution plate **322**. The source distribution plate includes a hole **324** disposed through the source distribution plate **322** and aligned with a central opening of the feed structure. The source distribution plate **322** may be fabricated from suitable conductive materials to conduct the RF and DC energy from the feed structure.

The source distribution plate **322** may be coupled to the target **306** via a conductive member **325**. The conductive member **325** may be a tubular member having a first end **326** coupled to a target-facing surface **328** of the source distribution plate **322** proximate the peripheral edge of the source distribution plate **322**. The conductive member **325** further includes a second end **330** coupled to a source distribution plate-facing surface **332** of the target **306** (or to the backing plate **346** of the target **306**) proximate the peripheral edge of the target **306**.

A cavity **334** may be defined by the inner-facing walls of the conductive member **325**, the target-facing surface **328** of the source distribution plate **322** and the source distribution plate-facing surface **332** of the target **306**. The cavity **334** is fluidly coupled to the central opening **315** of the body via the hole **324** of the source distribution plate **322**. The cavity **334** and the central opening **315** of the body may be utilized to at least partially house one or more portions of a rotatable magnetron assembly **336** as illustrated in FIG. **3** and described further below. In some embodiments, the cavity may be at least partially filled with a cooling fluid, such as water (H_2O) or the like.

A ground shield **340** may be provided to cover the outside surfaces of the lid of the process chamber **300**. The ground shield **340** may be coupled to ground, for example, via the ground connection of the chamber body. The ground shield **340** has a central opening to allow the feed structure to pass through the ground shield **340** to be coupled to the source distribution plate **322**. The ground shield **340** may comprise any suitable conductive material, such as aluminum, copper, or the like. An insulative gap **339** is provided between the ground shield **340** and the outer surfaces of the distribution plate **322**, the conductive member **325**, and the target **306** (and/or backing plate **346**) to prevent the RF and DC energy from being routed directly to ground. The insulative gap may be filled with air or some other suitable dielectric material, such as a ceramic, a plastic, or the like.

In some embodiments, a ground collar may be disposed about the body and lower portion of the feed structure. The ground collar is coupled to the ground shield **340** and may be an integral part of the ground shield **340** or a separate part coupled to the ground shield to provide grounding of the feed structure. The ground collar may be made from a suitable conductive material, such as aluminum or copper. In some embodiments, a gap disposed between the inner diameter of the ground collar and the outer diameter of the body of the feed structure may be kept to a minimum and be just enough to provide electrical isolation. The gap can be filled with isolating material like plastic or ceramic or can be an air gap. The ground collar prevents cross-talk between the RF feed (e.g., electrical feed **205**, discussed below) and the body, thereby improving plasma, and processing, uniformity.

An isolator plate **338** may be disposed between the source distribution plate **322** and the ground shield **340** to prevent the RF and DC energy from being routed directly to ground. The isolator plate **338** has a central opening to allow the feed structure to pass through the isolator plate **338** and be coupled to the source distribution plate **322**. The isolator plate **338** may comprise a suitable dielectric material, such as a ceramic, a plastic, or the like. Alternatively, an air gap may be provided in place of the isolator plate **338**. In embodiments where an air gap is provided in place of the isolator plate, the ground shield **340** may be structurally sound enough to support any components resting upon the ground shield **340**.

The target **306** may be supported on a grounded conductive aluminum adapter **342** through a dielectric isolator **344**. The target **306** comprises a material to be deposited on the substrate **304** during sputtering, such a metal or metal oxide. In some embodiments, the backing plate **346** may be coupled to the source distribution plate-facing surface **332** of the target **306**. The backing plate **346** may comprise a conductive material, such as copper-zinc, copper-chrome, or the same material as the target, such that RF and DC power can be coupled to the target **306** via the backing plate **346**. Alternatively, the backing plate **346** may be non-conductive and may include conductive elements (not shown) such as electrical feedthroughs or the like for coupling the source distribution plate-facing surface **332** of the target **306** to the second end **330** of the conductive member **325**. The backing plate **346** may be included for example, to improve structural stability of the target **306**.

The substrate support pedestal **302** has a material-receiving surface facing the principal surface of the target **306** and supports the substrate **304** to be sputter coated in planar position opposite to the principal surface of the target **306**. The substrate support pedestal **302** may support the substrate **304** in a central region **348** of the process chamber **300**. The central region **348** is defined as the region above the substrate support pedestal **302** during processing (for example, between the target **306** and the substrate support pedestal **302** when in a processing position).

In some embodiments, the substrate support pedestal **302** may be vertically movable through a bellows **350** connected to a bottom chamber wall **352** to allow the substrate **304** to be transferred onto the substrate support pedestal **302** through a load lock valve (not shown) in the lower portion of processing the chamber **300** and thereafter raised to a deposition, or processing position. One or more processing gases may be supplied from a gas source **354** through a mass flow controller **356** into the lower part of the chamber **300**. An exhaust port **358** may be provided and coupled to a pump (not shown) via a valve **360** for exhausting the interior of the process chamber **300** and facilitating maintaining a desired pressure inside the process chamber **300**.

An RF bias power source **362** may be coupled to the substrate support pedestal **302** in order to induce a negative DC bias on the substrate **304**. In addition, in some embodiments, a negative DC self-bias may form on the substrate **304** during processing. For example, RF power supplied by the RF bias power source **362** may range in frequency from about 2 MHz to about 60 MHz, for example, non-limiting frequencies such as 2 MHz, 13.56 MHz, or 60 MHz can be used. Optionally, a second RF bias power source (not shown) may be coupled to the substrate support pedestal **302** and provide any of the frequencies discussed above for use with the RF bias power source **362**. In other applications, the substrate support pedestal **302** may be grounded or left electrically floating. For example, a capacitance tuner **364** may be coupled to the substrate support pedestal for adjusting voltage on the substrate **304** for applications where RF bias power may not be desired.

A rotatable magnetron assembly **336** may be positioned proximate a back surface (e.g., source distribution plate-facing surface **332**) of the target **306**. The rotatable magnetron assembly **336** includes a plurality of magnets **366** supported by a base plate **368**. The base plate **368** connects to a rotation shaft **370** coincident with the central axis of the chamber **300** and the substrate **304**. A motor **372** can be coupled to the upper end of the rotation shaft **370** to drive rotation of the magnetron assembly **336**. The magnets **366** produce a magnetic field within the chamber **300**, generally parallel and close to the surface of the target **306** to trap electrons and increase the local plasma density, which in turn increases the sputtering rate. The magnets **366** produce an electromagnetic field around the top of the chamber **300**, and magnets **366** are rotated to rotate the electromagnetic field which influences the plasma density of the process to more uniformly sputter the target **306**. For example, the rotation shaft **370** may make about 0 to about 150 rotations per minute.

In some embodiments, the chamber **300** may further include a process kit shield **374** having an internal surface **380** facing the central region **348**. The process kit shield **374** may be connected to a ledge **376** of the adapter **342**. The adapter **342** in turn is sealed and grounded to the chamber wall **308**, which may be aluminum. Generally, the process kit shield **374** extends downwardly along the walls of the adapter **342** and the chamber wall **308** downwardly to below an upper surface of the substrate support pedestal **302** and returns upwardly until reaching an upper surface of the substrate support pedestal **302** (e.g., forming a u-shaped portion **384** at the bottom). Alternatively, the bottommost portion of the process kit shield need not be a u-shaped portion **384** and may have any suitable shape. A cover ring **386** rests on the top of an upwardly extending lip **388** of the process kit shield **374** when the substrate support pedestal **302** is in its lower, loading position but rests on the outer periphery of the substrate support pedestal **302** when it is in its upper, deposition position to protect the substrate support pedestal **302** from sputter deposition. An additional deposition ring (not shown) may be used to shield the periphery of the substrate **304** from deposition. Embodiments of a process kit shield are discussed below in accordance with the present invention.

In some embodiments, a magnet **390** may be disposed about the chamber **300** for selectively providing a magnetic field between the substrate support pedestal **302** and the target **306**. For example, as shown in FIG. **3**, the magnet **390** may be disposed about the outside of the chamber wall **308** in a region just above the substrate support pedestal **302** when in processing position. In some embodiments, the magnet **390** may be disposed additionally or alternatively in other locations, such as adjacent the adapter **342**. The magnet **390** may be an electromagnet and may be coupled to a power source (not shown) for controlling the magnitude of the magnetic field generated by the electromagnet.

A controller **310** may be provided and coupled to various components of the process chamber **300** to control the operation thereof. The controller **310** includes a central processing unit (CPU) **312**, a memory **314**, and support circuits **316**. The controller **310** may control the process chamber **300** directly, or via computers (or controllers) associated with particular process chamber and/or support system components. The controller **310** may be one of any form of general-purpose computer processor that can be used in an industrial setting for controlling various chambers and sub-processors. The memory **314**, or computer readable medium, of the controller **310** may be one or more of readily available memory such as random access memory (RAM), read only memory (ROM), floppy disk, hard disk, optical storage media (e.g., compact disc or digital video disc), flash drive, or any other form of digital storage, local or remote. The support circuits **316** are coupled to the CPU **312** for supporting the processor in a conventional manner. These circuits include cache, power supplies, clock circuits, input/output circuitry and subsystems, and the like. Inventive methods as described herein may be stored in the memory **314** as software routine that may be executed or invoked to control the operation of the process chamber **300** in the manner described herein. The software routine may also be stored and/or executed by a second CPU (not shown) that is remotely located from the hardware being controlled by the CPU **312**.

Thus, methods for depositing metals in high aspect ratio features formed on substrates have been provided herein. The inventive methods advantageously provide continuous coverage of surfaces of the high aspect ratio feature with metal while maintaining high process throughput and low substrate temperature. The inventive methods may be utilized with through silicon via (TSV) applications, for example, for either via first or via last methods of fabrication, as well as other suitable applications where depositing a continuous metal layer may be advantageous.

While the foregoing is directed to embodiments of the present invention, other and further embodiments of the invention may be devised without departing from the basic scope thereof.

The invention claimed is:

1. A method of processing a substrate in a physical vapor deposition (PVD) chamber, the substrate having an opening formed in a first surface of the substrate and extending into the substrate towards an opposing second surface of the substrate, the opening having an aspect ratio of height to width of at least 5:1, the method comprising:

applying a first RF power at a VHF frequency to a target comprising a metal disposed above the substrate to form a plasma from a plasma-forming gas;

applying DC power to the target to direct the plasma towards the target;

sputtering metal atoms from the target using the plasma while maintaining a first pressure in the PVD chamber sufficient to ionize a predominant portion of the metal atoms sputtered from the target;

depositing a first plurality of metal atoms on a bottom surface of the opening and on the first surface of the substrate;

applying a second RF power to a first electrode disposed beneath the substrate to redistribute at least some of the first plurality of metal atoms from the bottom surface to a lower portion of a sidewall of the opening; and

depositing a second plurality of metal atoms on an upper portion of the sidewall by reducing an amount of ionized metal atoms in the PVD chamber, wherein the first and second pluralities of metal atoms form a first layer deposited on substantially all surfaces of the opening.

2. The method of claim **1**, wherein depositing the first plurality of metal atoms further comprises:

applying a third RF power having a magnitude of up to about 50 watts to the first electrode to direct the first plurality of metal atoms towards the bottom surface of the opening.

3. The method of claim **2**, wherein the third RF power has a magnitude that is less than that of the second RF power.

4. The method of claim **1**, wherein at least some of the first plurality of metal atoms are redistributed from the upper surface of the substrate into the opening.

5. The method of claim **1**, wherein applying the second RF power to the first electrode to redistribute at least some of the first plurality of metal atoms further comprises:

maintaining the magnitude of the DC power to continue to sputter metal atoms from the target using the plasma while redistributing at least some of the first plurality of metal atoms to the lower portion.

6. The method of claim **1**, wherein applying the second RF power to the first electrode to redistribute at least some of the first plurality of metal atoms further comprises:

reducing the magnitude of or turning off the DC power to prevent sputtering of metal atoms from the target using the plasma while redistributing at least some of the first plurality to the lower portion.

7. The method of claim **1**, wherein applying the second RF power to the first electrode to redistribute at least some of the first plurality of metal atoms further comprises:

maintaining at least one of the first RF power or the first pressure to continue deposition of the first plurality on the first surface of the substrate and the bottom surface of the opening while redistributing at least some of the first plurality to the lower portion of the sidewalls of the opening.

8. The method of claim **1**, wherein applying the second RF power to redistribute at least some of the first plurality of metal atoms further comprises:

reducing the first pressure to a second pressure.

9. The method of claim **8**, wherein depositing the second plurality of metal atoms on the upper portion of the sidewalls further comprises:

reducing the second pressure to a third pressure to reduce the amount of ionized metal atoms in the PVD chamber.

10. The method of claim **1**, wherein depositing the second plurality of metal atoms on the upper portion of the sidewalls of the opening further comprises:

reducing the magnitude of the first RF power from a first magnitude to a second magnitude to reduce the amount of ionized metal atoms in the PVD chamber.

11. The method of claim **1**, wherein depositing the second plurality of metal atoms on the upper portion of the sidewalls of the opening further comprises:

reducing the magnitude of the DC power from a first magnitude to a second magnitude to reduce the amount of ionized metal atoms in the PVD chamber.

12. The method of claim **1**, wherein depositing the second plurality of metal atoms on the upper portion of the sidewalls of the opening further comprises:

reducing the magnitude of the second RF power to less than about 50 Watts.

13. The method of claim 1, further comprising:

etching the substrate to form the opening in the substrate; and

forming an oxide layer on the upper surface of the substrate and along the sidewalls and the bottom surface of the opening; and

forming a barrier layer atop the oxide layer prior to depositing metal atoms.

14. The method of claim 11, further comprising:

depositing a material atop the first layer to fill the opening by an electroplating process.

15. The method of claim 14, wherein the deposited material and the metal are the same material.

16. The method of claim 14, wherein the substrate is a first substrate and further comprising:

providing a second substrate disposed adjacent to the second surface of the first substrate, wherein the opening extends completely through the first substrate and an upper surface of the second substrate forms the bottom of the opening.

17. The method of claim 14, further comprising:

removing the bottom surface of the opening to expose at least one of the first layer or the deposited material.

18. The method of claim 17, wherein removing the bottom surface of the opening further comprises:

at least partially removing the second surface of the substrate by chemical mechanical polishing to remove the bottom surface of the opening.

19. The method of claim 18, further comprising:

coupling the second surface of the substrate to an upper surface of a second substrate.

20. The method of claim 19, wherein coupling the second surface of the substrate further comprises:

aligning the opening with a corresponding device disposed in the upper surface of the second substrate.

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